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THE BEAN THRIPS

STANLEY F. BAILEY

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THE BEAN THRIPS[1]

STANLEY F. BAILEY[2]

THE BEAN THRIPS, *Hercothrips fasciatus* (Perg.), has been known as a pest in California since 1882 and is doubtless a native insect. It is a major problem on beans and cotton in the Sacramento and San Joaquin valleys. In the dry, interior valleys of central and northern California it also frequently injures pears. It sometimes attacks ornamentals and many other crops in various parts of the state. In central California it has increased in importance during the last fifteen years in the great valleys, particularly on reclaimed land. Where large acreages of beans have been attacked, control by insecticides has been difficult and often unsatisfactory. Based upon a detailed study of the biology of this insect made in 1929–1932, experimental control work has been conducted during the past four years. The results are reported here together with additional information on the distribution and ecology of the insect. As is evident to those familiar with the previous publication[3] much of the original material on the life history is again presented. This has been deemed advisable since the above-mentioned report has not found its way into the hands of many who are concerned with this pest. An attempt has been made to bring together under one cover all the pertinent facts concerning the bean thrips.

HISTORY AND DISTRIBUTION

The bean thrips was the first thrips recorded from California (Bailey, 1936*a*)[4] and as early as 1882 was recognized as injurious in Solano County. Not until 1895 was it described, from Yuba County, by Pergande. Bremner (1910) appears first to have given to *Hercothrips fasciatus*[5] the name "bean thrips" by which it has since been known. Russell (1912*b*) first studied the life cycle of this insect and reviewed what was known of its early history. A brief discussion of the distribution and probable origin was given in 1933 by the present writer.

References not cited in the two above-mentioned publications, together with new records, are presented here to make available all known records of this pest. Merrill (1912) mentioned extensive outbreaks on beans in

[1] Received for publication February 20, 1937.

[2] Instructor in Entomology and Junior Entomologist in the Experiment Station.

[3] Bailey, Stanley F. The biology of the bean thrips. Hilgardia 7(12):467–522. 1933.

[4] See "Literature Cited" at the end of the paper for complete data on citations, which are referred to in the text by author and date of publication.

[5] The synonymy of the bean thrips briefly is as follows:

Heliothrips fasciata Pergande, 1895	*Euthrips fasciatus* Bremmer, 1910
Heliothrips fasciatus Hinds, 1902	*Hercothrips fasciatus* Hood, 1927
Caliothrips woodworthi Daniel, 1904	

Sutter County. H. S. Smith (1915) and Essig (1917) listed the bean thrips as a minor pest of olives. Morrill (1917) was first to note this insect in Arizona, where it was injuring beans. According to Burrill (1918) the bean thrips caused large losses to beans and other crops in Idaho. Watson (1920, 1921) found it in Florida. In 1925 Morrill re-

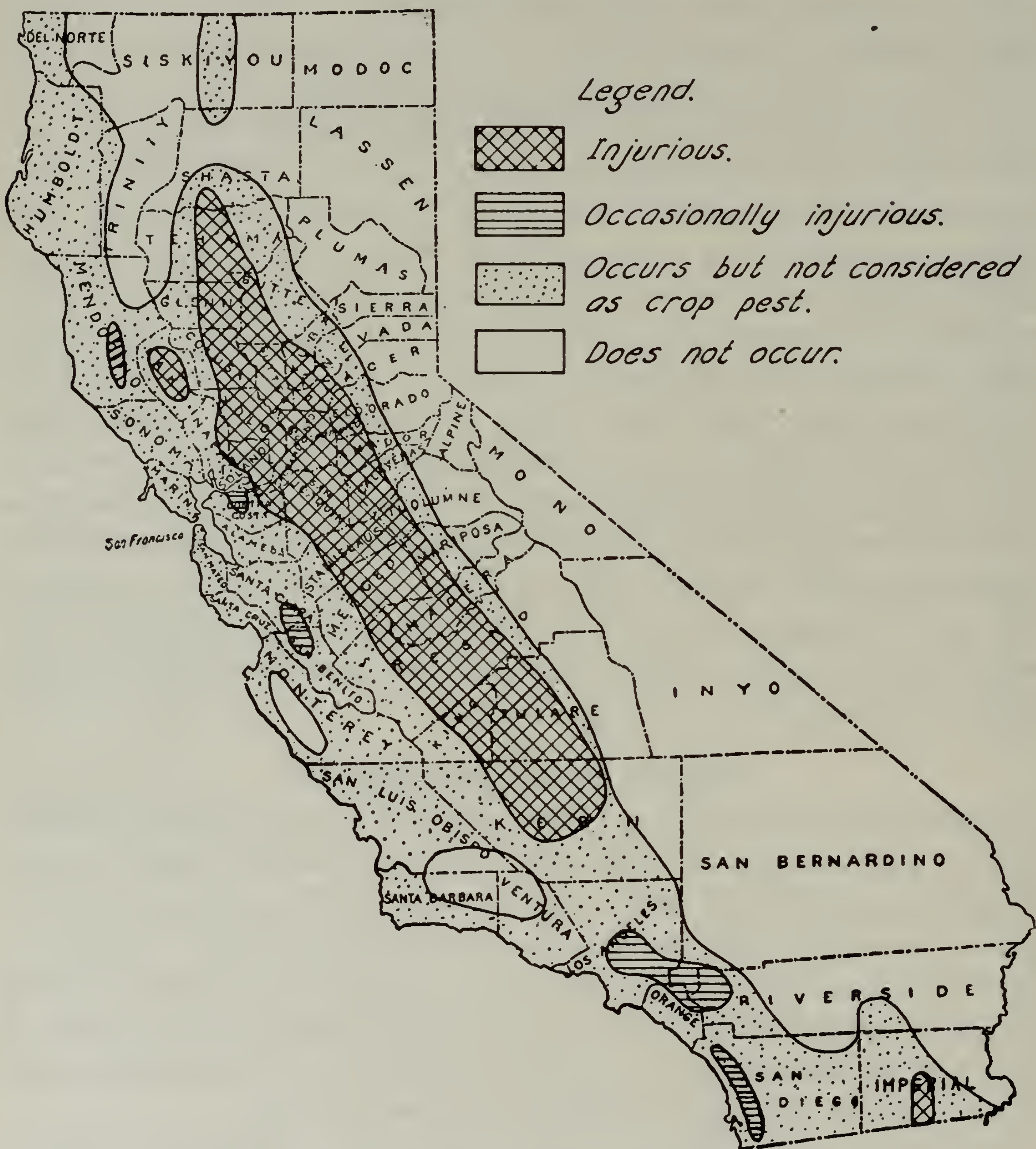

Fig. 1.—Distribution of the bean thrips in California.

ported injury to peas on the west coast of Mexico. Many cases of damage are at hand, and during 1927–1930 pears were severely defoliated in Berryessa Valley (Napa County) and Lake County (see Stokes, 1931, and Bailey, 1933). Pack (1930) noted serious damage to beans in Utah (see also Knowlton, 1932).

In the last three or four years, in Stanislaus County (Westside district), and also on reclaimed land in the Sutter Basin (Mackie, 1936),

the problem has increased in importance. In September, 1935, this thrips injured beans at Powell, Wyoming (Bailey, 1936*b*). List and Newton (1936) report it from Colorado. The most recent development in California is the damage to string beans for canning, in the Upper Lake district of Lake County.

The map (fig. 1) indicates as accurately as possible the present known distribution of the bean thrips in California.

In North America definite records are available from the following states: California, Oregon,[6] Nevada, Idaho, Utah, Wyoming, Arizona, Colorado, Florida, and South Carolina. Doubtful or unconfirmed records are at hand from New York,[7] Tennessee (Morgan, 1913), Texas, Alabama, Louisiana, and Mississippi. In certain cases the hibernating adults have been taken from California oranges received in various eastern states, Nebraska in 1899, and Illinois in 1907, and at various foreign points of consignment, particularly in Japan and Hawaii (for references see Bailey, 1933). Foreign distributional data come from China, the west coast of Mexico (Morrill, 1925), and Argentina (Blanchard, 1936). Questionable foreign records are listed from Brazil, Philippine Islands, Spain, Italy, and Palestine. Priesner (1928) believed that the occurrence of the bean thrips in Europe needed confirmation. Whether or not this insect is increasing its range or whether it is now more frequently recognized because of a wider knowledge of thrips is difficult to ascertain; the latter case is more probable.

HOSTS

Like most thrips of economic importance, the bean thrips is found on many plants. The greater number of the hosts may be classed, however, as chance or transitional. Also, certain plants and parts of plants are used as hibernating quarters only. A true host plant is here considered to be one on which the egg, larval, and adult stages are found (the pupal stage being passed in the soil). No attempt is made to classify the various native hosts as summer or winter hosts. The lists of plants given below are arranged alphabetically for convenience. Certain greenhouse plants not readily classified as crops or ornamentals in North America but known to support bean thrips are banana, lime, and loquat.

[6] Collected by the writer near Ashland, Oregon, August, 1934.

[7] Information on distribution in this paragraph was obtained from Quayle (1914) and from correspondence as follows:

Letter from J. A. Hyslop, Bureau of Entomology, U. S. Department of Agriculture, August 18, 1936.

Letter from F. L. Thomas, College Station, Texas, August 20, 1936.

Letter from the late W. E. Hinds, Baton Rouge, Louisiana, March 30, 1931.

Letter from D. Moulton, Redwood City, California, August 26, 1936. Moulton believes the species from Brazil to be *Hercothrips ipomoeae* Moulton.

Crop Plants Serving as Hosts to Bean Thrips[8]

Alfalfa*	Cauliflower	Lettuce*	Persimmon
Almond	Clover	Melons	Plum
Apple	Corn	Olive	Potatoes
Asparagus	Cotton*	Onions	Prune
Avocado	Figs	Orange	Radishes
Beans*	Garlic	Peach	Swiss chard
Beets	Grape	Pear (Bartlett, particularly)*	Tangerine
Cabbage	Hops		Tomatoes
Cantaloupes*	Kale	Peas*	Turnips
Carrots	Leek	Peppers	Walnut

Partial List of Wild and Ornamental Plants Serving as Hosts for Bean Thrips

Acacia sp.
Aesculus californica (buckeye)
Althea rosea (hollyhock)
Amaranthus retroflexus (rough pigweed)
Anthemis cotula (mayweed)
Arundinaria japonica (bamboo)
Asclepias mexicana (milkweed)
Aster sp.
Atriplex sp. (saltbush)
Bidens pilosa (bur marigold)
Brassica campestris (common yellow mustard)
Canna sp.
Caragana sp.
Cassia sp.
Chenopodium murale (nettle-leaf goosefoot)
Cirsium edule (Indian thistle)
Convolvulus arvensis (morning-glory)
Crepis sp. (hawksbeard)
Cupressus sp. (cyprus)
Dahlia sp.
Digitalis sp. (foxglove)
Echinocystis sp.
Erigeron canadensis (horseweed)
Erodium cicutarium (red-stem filaree)
Eschscholtzia californica (California poppy)
Foeniculum sp. (fennel)
Geranium sp. (cranesbill)
Gladiolus sp. (gladiolus)
Gnaphalium decurrens var. *californicum* (California everlasting)
Helianthus annuus (common sunflower)
Heliotropium currassavicum (Chinese pusley)
Hemizonia sp. (tarweed)
Iris spp.
Lactuca scariola (prickly lettuce)
Laurestina sp.
Lotus americanus (Spanish clover)
Lotus scoparius (deerweed)
Lupinus sp.
Malva parviflora (mallow)
Medicago hispida (bur clover)
Melilotus alba (white melilot)
Mentha sp. (mint)
Mentzelia laevicaulis (blazing star)
Mirabilis laevis (wishbone bush)
Montia perfoliata (miner's lettuce)
Nicotiana glauca (tree tobacco)
Photinia arbutifolia (toyon)
Pinus sp.
Polygonum aviculare (wire grass)
Pueraria hirsuta (Kudzu)
Pyracantha sp. (firethorn)
Quercus agrifolia (coast live oak)
Quercus lobata (valley oak)
Rosa spp.
Sonchus oleraceus (common sow-thistle)
Stellaria media (common chickweed)
Tacsonia mollisima (passion flower)
Tropaeolum majus (nasturtium)
Tulipa sp.
Verbascum virgatum (mullein)
Vicia sp. (wild vetch)

[8] The crops starred are subject to serious loss by bean-thrips infestations.

In certain localities in California temperature and rainfall are favorable for this insect but during the summer there are no suitable succulent host plants. Where only wild oats, mustard, native grasses, and other early annual or desert plants form the cover, no green hosts remain in July, August, and September. Willow and cottonwood are not summer host plants. In this type of environment the bean thrips cannot survive. Where a few scattered plants of blazing star, mallow, California poppy, or even buckeye are present, the thrips can maintain themselves.

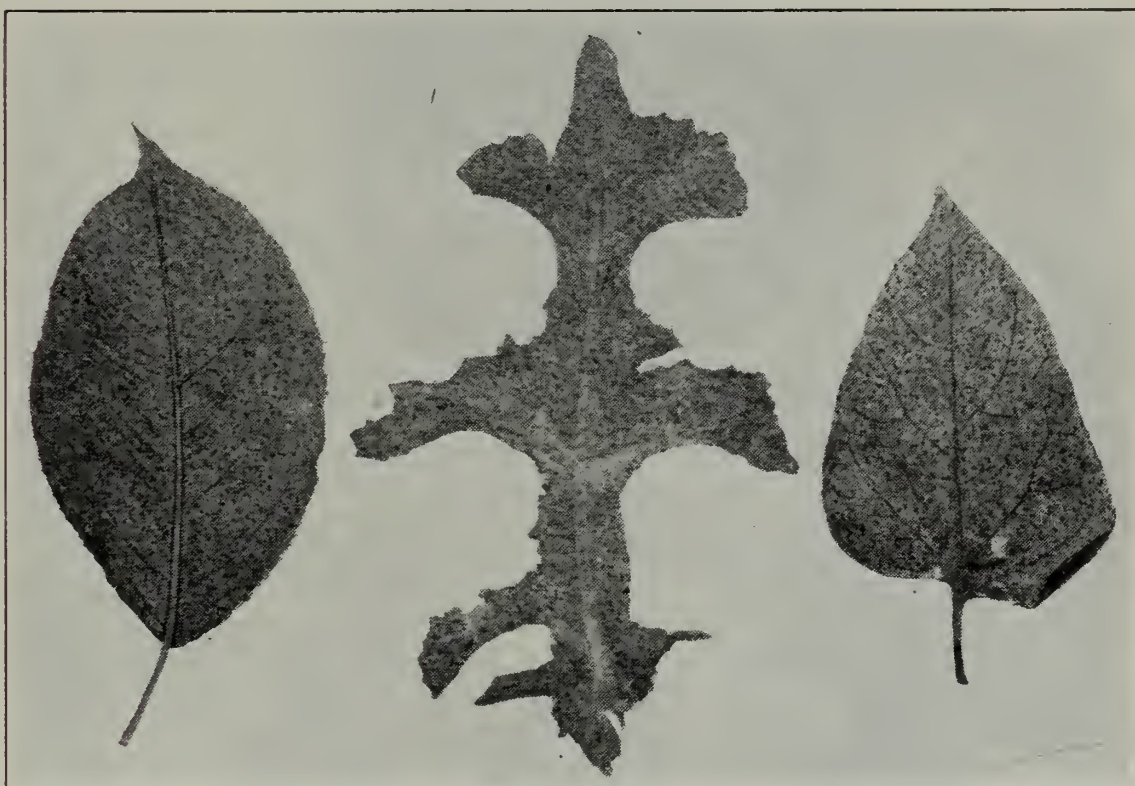

Fig. 2.—Injury caused by bean thrips. Left to right: pear, prickly lettuce, bean. Note silvering and black dots of excrement.

The two generally preferred weed hosts, prickly lettuce and common sow-thistle, are native to Europe. They occur very commonly in fields and waste places, particularly in valleys throughout California, and have spread rapidly in irrigated districts.

INJURY AND ECONOMIC IMPORTANCE

The chief injury from the bean thrips is the premature defoliation of beans, cotton, and pears. The condition is produced by the feeding of the larvae and adults. The insect is naturally gregarious. As the mouth parts of both feeding stages are constructed primarily for sucking, only liquid food is taken into the body. The effect of feeding on the surface of a leaf or fruit is a silvering or bleaching (figs. 2, 3, 4). Injured tissue

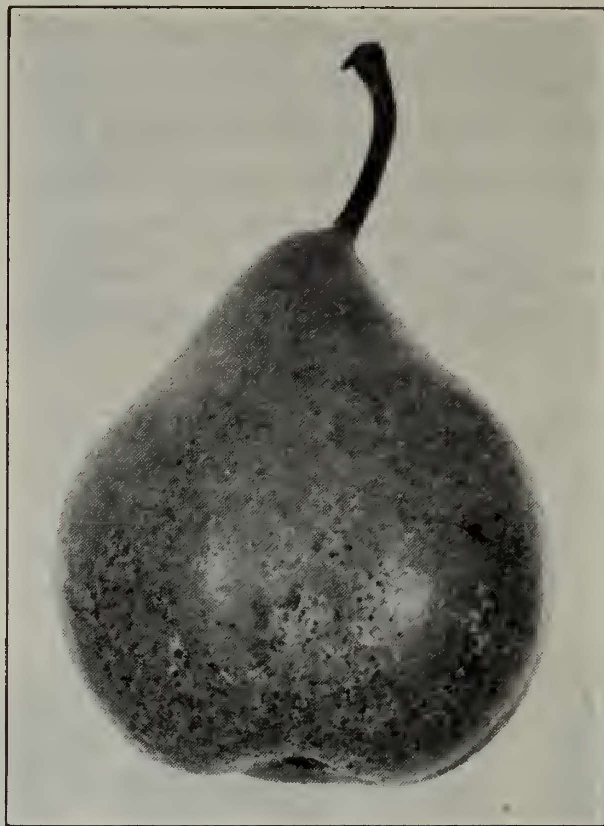

Fig 3.—Injury to pear fruit by bean thrips. Note speckling on lower half of fruit caused by surface feeding and deposition of excrement.

Fig. 4.—Injury to cotton by bean thrips, resulting often in defoliation.

often becomes papery and wilts rapidly, particularly if suffering from a lack of water. Annual plants are often killed by continued feeding. Deciduous trees, on the other hand, are prematurely defoliated, often in the lower half; and frequently the fruit and the new wood sunburn. Naturally the trees are somewhat weakened for the following season.

The tiny black dots of excrement on the fruit in addition to the silvering render it unmarketable (fig. 3). Pears, string beans (fig. 5), peas,

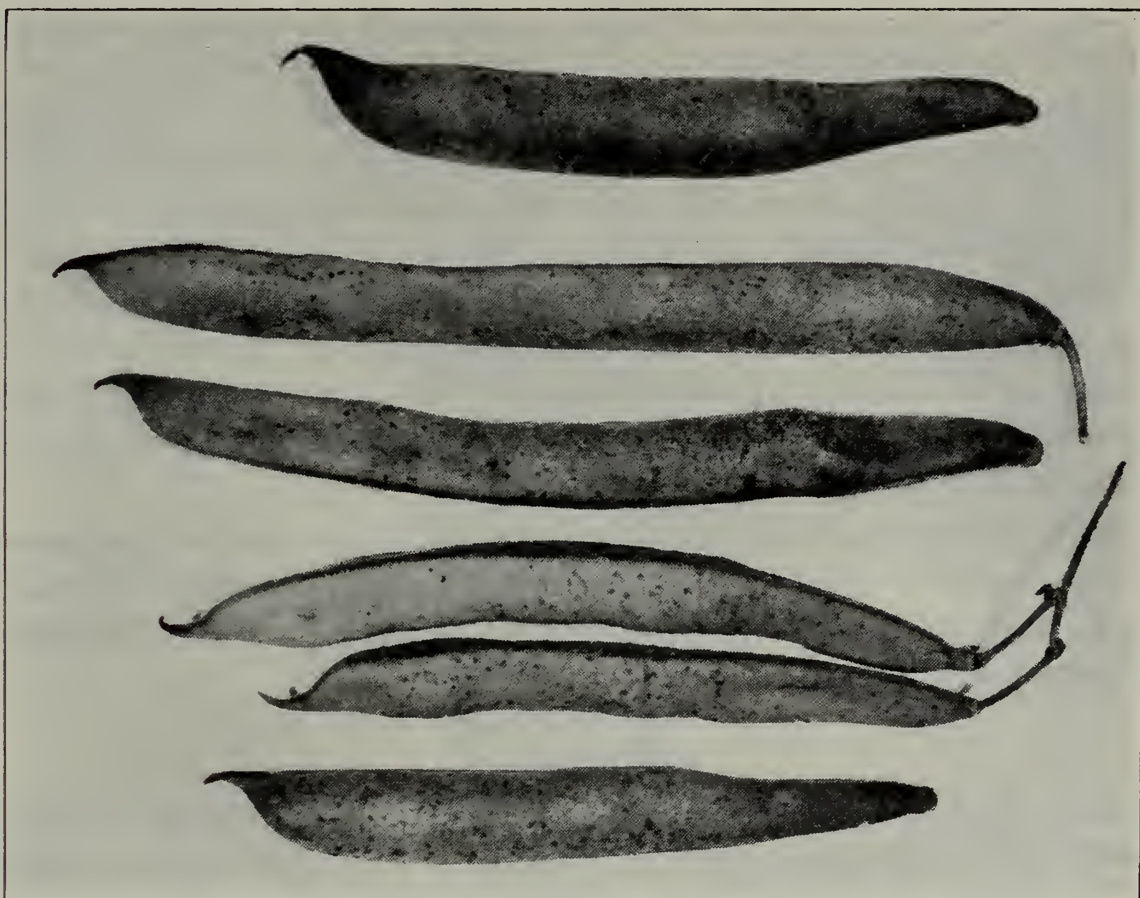

Fig. 5.—Injury to string beans by bean thrips, showing silvering and dots of excrement.

and certain ornamental flowers are particularly subject to such injury. In 1930 one large orchard in Napa County had 15 per cent of the pears injured thus, and other orchards in the past have sustained as high as 75 per cent loss. The minute oviposition scars are practically invisible and of little consequence.

Though the bean thrips has been listed as a citrus pest, R. S. Woglum, Entomologist of the California Fruit Growers' Exchange, stated (1931) that he had "never up to the present time observed this insect as an economic pest of citrus fruits." Because it congregates in large numbers on the leaves and fruit of citrus (particularly the navel end) in the autumn, however, the Board of Commissioners of Agriculture and Forestry of Hawaii require all citrus fruits entering the Territory between

September 1 and March 31, inclusive, to be fumigated.[9] In a letter dated July 8, 1936, Mr. Woglum informed the writer: "We have never observed bean thrips injuring fruit in storage or transit. As a matter of fact it does little or no damage to the fruit in the field. I have seen a little scarring at Edison, where the bean thrips congregated in tremendous numbers on the outside of the fruit in October while the fruit was still green, causing a silvery appearance in spots where they were present. In general, its damage to citrus is of no economic consideration."

The loss to a crop cannot easily be estimated in accurate monetary terms. Varying degrees of injury occur all the way from a total loss to a slight reduction in amount or quality. In addition, yearly variation in degree of infestation, cultural practices, type of soil, time of planting, length of growing season, and other factors influence the degree and extent of injury. Burrill (1918) stated that annual losses from this pest in Idaho were very great. Mackie (1936) pronounced the bean thrips "the most important insect pest" of beans in Sutter County, California, during 1935. In very dry seasons the damage is both severe and widespread in the interior irrigated sections of the state. Some loss is occasioned every year to pears, cotton, and beans.

Three or four species of thrips have recently been shown to be vectors of plant viruses. Thus far the bean thrips has not been implicated as a vector of any virus, though its chief host, prickly lettuce, is susceptible to spotted wilt, a thrips-transmissible virus.

DESCRIPTION[10]

Adult.—The adult bean thrips (fig. 6) is dark grayish black and about 1 millimeter long (approximately $\frac{1}{25}$ inch). The forewings are banded with two light and two dark areas. The hind wings are a uniform grayish brown. When the wings are folded lengthwise over the body the insect appears to the naked eye to be grayish black with two white bars across the center. The legs and antennae are also banded with alternate light and dark areas. Both pairs of wings have a long posterior fringe. The

[9] Rule 29, Regulation 5 (a). Board of Commissioners of Agriculture and Forestry, August 30, 1930.

"Citrus fruits: To be eligible for entry at Territorial ports during the specified period all citrus fruits shall have been fumigated with hydrocyanic acid gas, in a gas tight fumigator or refrigerator car with a dosage of not less than 2–3 oz. sodium cyanide or equivalent per hundred cubic feet of enclosed space, for not less than 35 minutes.

"It is specifically understood that the fumigation dosage and procedure provided for in the foregoing paragraph is prescribed solely against the bean thrips, and all shipments of citrus fruits offered for entry at Territorial ports, found upon inspection to be infested with other insects, including the citrophilus and maritime mealybugs, shall be subject to rejection."

[10] For a technical description of the various stages of the bean thrips see: Bailey, Stanley F. The biology of the bean thrips. Hilgardia 7(12):468–73. 1933.

body is bluntly rounded at the posterior end. The male, slightly smaller than the female, can be readily distinguished under the microscope by transparent elliptical areas on the underside of abdominal segments 3–7.

Larva.—The larvae of the bean thrips are reddish yellow or pink. When first hatched (fig. 7, *B*) they are nearly translucent white; when mature they are often deep crimson and always have the same general

Fig. 6.—The adult female of the bean thrips.

shape as the adult (fig. 7, *C*). Wings are lacking. Larvae are usually seen feeding together with the adults in groups on the leaves. These two stages, the most commonly seen, are the feeding stages. The egg (fig. 7, *A*), which is deposited within the leaf tissue, is bean-shaped, white, and very delicate. Being only about 0.2 mm long it cannot be seen with the unaided eye. The pupal stage (fig. 7, *D* and *E*), which is passed in the soil, is mobile if disturbed and in appearance resembles the larva. The antennae and wing buds are swollen and are folded over the head and along the sides of the abdomen respectively. The crimson blotches are retained but gradually disappear as the adult matures.

Other Species of Thrips Found on Beans, Cotton, and Pears in California.- -Besides *Hercothrips fasciatus,* one of the most frequently en-

countered thrips on beans is a species of flower thrips, *Frankliniella occidentalis* (Perg.). This species occurs in all bean-growing areas and is commonly found in the blossoms, often weakening them by feeding upon the flower parts. When present in large numbers this thrips injures

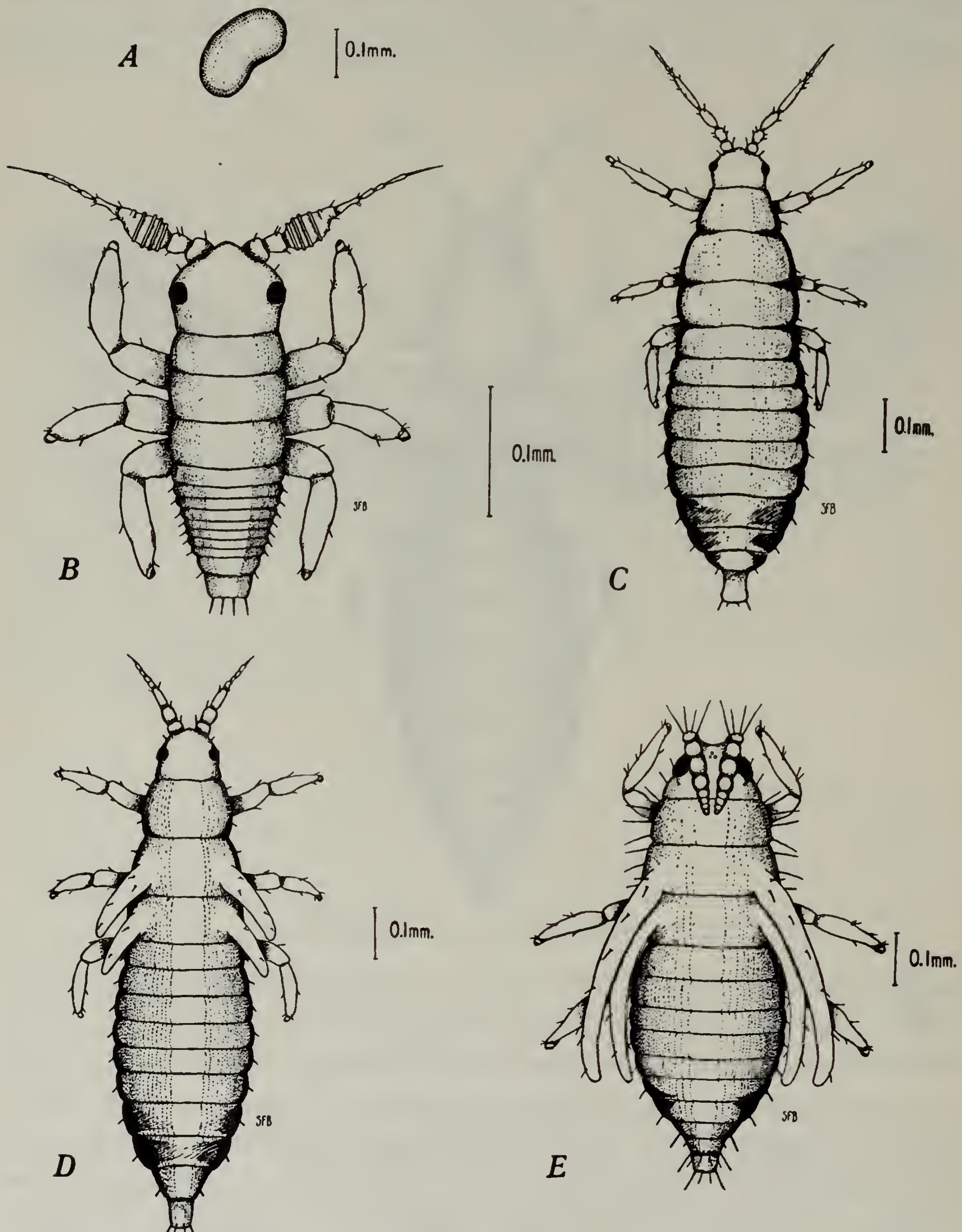

Fig. 7.—The bean thrips. *A*, Egg; *B*, newly emerged larva; *C*, mature larva; *D*, prepupa; *E*, pupa. (From *Hilgardia* Vol. 7, No. 12.)

the foliage as seriously as the bean thrips itself. Usually *F. occidentalis* is common in the spring and early summer but much less abundant during the hot weather. Exceptions are known, however, in the Sacra-

mento Valley and along the coast. The onion thrips, *Thrips tabaci* Lind., though common on beans, is rarely injurious. Other species found on beans in California are *Frankliniella moultoni* Hood, *F. minuta* Moulton, *Thrips nigropilosus* Uzel, and the sugar-beet thrips, *Hercothrips femoralis* (Reuter). The greenhouse thrips, *Heliothrips haemorrhoidalis* (Bouché), often appears on beans growing under glass. Three predaceous species of thrips—namely, *Scolothrips sexmaculatus* (Perg.), *Aeolothrips fasciatus* (L.), and *A. kuwanaii* Moulton—are also reported from this crop.

The species of thrips found on cotton in California are not numerous. Aside from the bean thrips, *Heliothrips haemorrhoidalis* (Bouché), *H. fasciapennis* Hinds, *Frankliniella occidentalis* (Perg.), *F. moultoni* Hood, *Thrips tabaci* Lind., and *Scolothrips sexmaculatus* (Perg.) have been taken from cotton. *H. fasciapennis* has been recorded as injurious only once (Morgan, 1913). *F. occidentalis* is often numerous enough in late spring and early summer to injure the leaves of young cotton plants.

On pears, however, many more species are found. Besides the bean thrips the only injurious species are the pear thrips, *Taeniothrips inconsequens* (Uzel), and *Frankliniella* species. These thrips are known to injure pears in the spring only and would not be confused with the bean thrips. As far as the writer knows, the following additional species include all other thrips listed from pears in California: *Aeolothrips fasciatus* (L.), *A. kuwanaii* Moulton, *Chirothrips aculeatus* Bagnall, *Sericothrips variabilis* (Beach), *Scirtothrips citri* Moulton, *Taeniothrips costalis* (Jones), *Rhopalandrothrips corni* Moulton, *Thrips tabaci* Lind., and *Leptothrips mali* (Fitch).

LIFE HISTORY AND HABITS

The life history of the bean thrips is typical of many plant-feeding Thysanoptera. Most thrips of economic importance whose life history is known are general plant feeders and have several generations a year. The majority of the species are bisexual, and the adults are rather active. Eggs are deposited in plant tissues; and the larvae feed gregariously in protected parts of buds, flowers, and the like. Pupation normally occurs in the soil beneath the host. There are several overlapping generations during the summer, but the winter is usually passed in the adult stage.

HABITS OF THE ADULT

Hibernation.—About the last of October the adults of the bean thrips, at this time extremely numerous in infested areas, seek out protected places in which to pass the winter. They migrate chiefly to plants that are still green and become largely inactive. Egg-laying ceases in early

October, and larvae normally disappear by the middle of the month. None of the immature stages survive November.

Hibernation is doubtless chiefly a reaction to cold since inactivity of adults can be induced by artificially lowering the temperature. Both entrance into and emergence from hibernation are gradual. On exceptionally warm winter days (maximum temperature 75°–80° F) some activity and a little feeding occur. Thus one can see why this thrips prefers a live winter host.

Local conditions regulate both the place and the duration of hibernation. In the San Joaquin Valley, near large cultivated areas, the adults migrate to the margins of the field just before and during harvest and pass the winter in and about the fields on such green plants as offer protection. A principal winter host in this area is the annual sow thistle; and adults are frequently found in numbers on ornamentals and alfalfa near bean and cotton fields. In more wooded regions and at higher altitudes, as in Lake, Placer, and El Dorado counties, many adults hibernate on evergreen trees and shrubs adjacent to orchards and gardens. In citrus-growing areas adults often hibernate in the navel end of oranges. The most suitable quarters are under old scale insects; in curled leaves or on the underside of hairy leaves of live oak; on toyon, pine cones, some winter annuals, and ornamentals near residences. The overwintering individuals suffer a high mortality, chiefly from the rain; and only those in well-protected places above the ground survive. Low temperatures (16° F) have very little effect on the dormant adults in California.

Egg Laying.—With the swordlike ovipositor the female inserts the eggs in or just beneath the epidermis of the plant. Eggs are laid in the petioles of leaves and flowers, on both upper and lower surfaces of the leaves, and even in the surface of young fruit and pods if very tender. The lesion formed by the ovipositor is minute (about 0.25 mm). The presence of eggs may be ascertained under magnification by small translucent bumps on the surface. Egg laying begins about the first of April and continues till late in September. The females are usually found ovipositing on the more succulent portions of the plant which are free from signs of feeding. Frequently, dead females are found with the ovipositor caught in the epidermis. The number of eggs laid by an individual varies. Russell (1912*b*) stated that females sometimes oviposit over a period of 83 days and lay a maximum of 134 eggs. During the summer the average longevity of an adult bean thrips is about three weeks, and egg laying continues somewhat irregularly throughout life. Most females lay 30 to 50 eggs each during this period.

Other Habits of the Adult.—Newly emerged adults remain inactive for about 24 hours in the soil, probably to allow the exoskeleton and the

muscles to harden. The females emerge 10 to 30 hours before the males from pupae of the same age.

The adult bean thrips have very little ability to force their way up through compact soil. They gain the surface largely through cracks and porosities. If the structure and position of the soil particles are altered (as by irrigation or cultivation) after the mature larvae have pupated, the adults cannot easily reach the surface, and usually die.

The bean thrips feeds by sucking plant juice. The actual feeding process, however, has often been described as a combined rasping and sucking. Only the surface layers of cells of the plant are affected since the extrudable mouth parts can penetrate only about 0.03 mm. The area fed over presents a silvery or blasted appearance because the cell contents have been sucked out. The larvae feed in the same manner as the adults.

Mating does not take place until the newly emerged adults have fed one or two days; it may occur intermittently throughout life. Egg laying may begin as early as the third day after emergence, and unfertilized females have sometimes laid eggs on the fourth day after emerging.

Three types of reproduction are known among various species of thrips, namely: bisexual (apparently the normal form), asexual, and facultative, an alternation of both the bisexual and asexual methods. Under normal conditions the bean thrips reproduces bisexually, and males are found throughout the year. If, however, males are not present, the females can reproduce without mating. Unfertilized females always produce male offspring. Fertilization is apparently the normal condition and explains the preponderance of females found in the field—about two to one—since mated females produce nearly all females.

The power of flight of the adult bean thrips is not great. The wings, thought fully developed, are little used. Besides flying, the adults can hop or jump. The distance to which they hop seldom exceeds 10 or 12 inches. With their wings, however, they can make a rather weak, zigzag flight of 3 or 4 feet. They move from plant to plant chiefly by hopping. Their migrations from wild hosts to crops are entirely local and are rarely from distances greater than 100 yards. The movement is gradual, often aided by winds. Many short hops and flights are necessary to carry the migrants any distance. Field observations employing tanglefoot-paper sheets in the path followed by the thrips to young beans from a stubble field indicate that the movement is seldom above 2 feet from the ground. The migrating adults, by many intermittent hops and short flights, appear to encounter the plants by chance. If they come to rest on a suitable plant, they may feed and oviposit. If not, they move on to an adjacent plant. Thus a migration is gradual and might be regarded

as an infiltration. The manner of dispersal in the field then is irregular, and depends on the amount and direction of the air currents and upon the source of the original infestation.

In the field the length of life varies with the season. Hibernating adults live as long as 5 months during the winter. In the summer the average life of the mature insect is about 3 weeks. Without food or water life cannot exist much longer than 24 hours. Newly emerged adults may live 3 days without food. As mentioned above, the natural mortality of hibernating adults is rather high and is difficult to determine accurately in the field. Woglum and Lewis (1936) found the mortality in the navel end of oranges to be 16.4 per cent.

TABLE 1*

Effect of Temperature on the Larval Stage

Number of mature larvae	Temperature, deg. Fahr.	Average length of instars, days		Average length of larval stage, days	Per cent total development per day	Average mortality, per cent
		First	Second			
60	60	18.0	15.0	33.0	3.3	57.0
60	70	5.4	8.2	13.6	7.4	31.6
65	80	5.0	4.0	9.0	11.1	21.5
35	90	4.3	3.8	8.1	12.3	52.4
45	100	3.0	2.0	5.0	20.0	81.5

* From: Bailey, Stanley F. The biology of the bean thrips. Hilgardia 7 (12):508. 1933.

HABITS OF THE IMMATURE STAGES

Larval Stage.—When ready to hatch, the egg swells and splits lengthwise in the thoracic region of the embryo. The head of the emerging larva appears first, and the remainder of the body wriggles out rapidly. Feeding commences at once. Most of the larvae are found on the undersides of the leaves in clusters. As the underside becomes fed over, they move to the upper side. The lower leaves on the host plants are thus injured first; and as the season progresses the infestation works up on the host to the newer and more tender leaves. Adults and larvae feed together, the proportion being about five larvae to one adult. The larvae characteristically carry the tip of the abdomen slightly elevated, usually with a drop of excrement resting upon it.

There are two larval stages. When the insect is about half grown one molt occurs on the host. A second skin is shed when the mature larva molts to the prepupal stage in the soil. The mature larva is about the size of the adult and relatively sluggish. After dropping off the host—usually during the night—it crawls down into the top soil from 3 to 6 inches, comes to rest in a suitable crack or niche, and then molts.

The length of the larval stage varies with the temperature. During the summer under field conditions in the Sacramento Valley, the larval stage consumes about 10 days. Table 1 shows the effect of temperature on the larval development.

As the lowest mortality (21.5 per cent) occurs at 80° F (constant temperature), evidently this temperature is the most favorable for the increase of the species.

TABLE 2*

EFFECT OF TEMPERATURE ON THE PUPAL STAGE

Number of mature larvae	Temperature, deg. Fahr.	Average length of prepupal period, days	Average length of pupal period, days	Average length of prepupal and pupal periods, days	Per cent total development per day	Average mortality, per cent
50	28	....	....	....	0.0	100.0
316	30	....	....	....	0.0	100.0
50	40	....	....	....	0.0	100.0
60	50	12.0	....	....	0.0	100.0
75	60	9.5	14.0	23.5	4.2	94.0
80	70	1.6	9.3	10.9	9.1	78.6
100	80	1 0	3.0	4.0	25.0	50.0
75	90	0.9	2.4	3.3	30.3	50.0
108	100	1.0	1.8	2.9	34.4	65.7
50	110	0.8	....	....	0.0	100.0

* From: Bailey, Stanley F. The biology of the bean thrips. Hilgardia 7 (12):511. 1933.

Pupal Stage.—The so-called pupal stage of the Thysanoptera is not a true resting stage in that the thrips pupa is mobile in most species. It takes no food, however; some species form a cell; and according to recent studies certain groups spin cocoons. The larva of the bean thrips, after dropping to the ground and becoming established in a suitable crack or niche, molts to a prepupal stage. At this time the antennae become thicker, and the wing stubs appear at the sides of the prothorax. The prepupal stage lasts only a short time—1 or 2 days—according to the temperature; then another molt occurs. Next comes the pupal stage, robust and somewhat paler. The antennae are folded back over the head; and the wing pads, greatly lengthened, extend downward along the sides of the abdomen. Under optimum conditions the pupal stage lasts about 3 days. Table 2 shows how temperature affects this stage.

The depth at which pupation occurs in the soil appears dependent upon several factors, chiefly the type and condition of the soil and the soil temperature. In cultivated pear orchards, under normal conditions, pupation occurs 3 to 6 inches below the surface. No cell is made, and the pupae are found singly or clustered in small groups. Larvae and pupae within 3 inches of the surface do not survive in the summer in unshaded

soil because of high surface-soil temperatures. In dense weed patches, however, and under bean plants where the soil is well shaded, pupae have been found on top of the ground and even in curled leaves under the plants. Where the ground cracks deeply or other conditions offer easy access, pupation has been observed as deep as 15 inches in the soil. If, on the other hand, the top soil is very fine, dry, or sandy, the larvae cannot well force their way downward. Under such conditions, because of high temperature and desiccation, a heavy mortality results. Crops grown in very sandy soil are infrequently attacked. In bean and cotton fields pupation normally occurs under the plants, chiefly on the ridges rather than in the furrows, where irrigation and cultivation make for unfavorable conditions.

Mortality of Immature Stages.—Under natural conditions the immature stages of the bean thrips have a high mortality. As was mentioned above, the ratio of larvae to adults on the host plants is about five to one. Daily counts, totaling 9,143 mature larvae, in the summer of 1930 showed a 60.3 per cent mortality (including 0.9 per cent parasitized). Mortality is highest in the larval stage. In the laboratory it was 34.1 per cent among the mature larvae, 0.3 per cent in the prepupal stage, and 16.5 per cent in the pupal stage. Only about 40 per cent of the mature larvae ever become adults. Heavy summer rains greatly reduce the number by actually beating larvae off the plants. The delicate forms in the soil are readily killed from the shifting and packing of the soil particles by the rain.

In addition, the bean thrips suffers some mortality in the egg stage, primarily from two sources: predacious thrips and wilting or drying of the leaves or plant tissue in which the egg is deposited. In the latter case, either the egg itself becomes desiccated or the larva cannot force its way out of the dried epidermis when ready to hatch.

SEASONAL CYCLE

A knowledge of seasonal history is essential to intelligent and satisfactory control. Although the habits of the bean thrips are in general the same throughout its distribution in California, local conditions affect the seasonal history and the sequence of infestations.

In the dry, interior, nonirrigated valleys where pears are attacked, the infestation and injury are usually not noticed before the middle of July. The winter is passed in the adult stage on such plants, shrubs, and trees as are green at that season. The most suitable hibernating quarters are found in curled leaves or on the underside of pubescent leaves of such winter hosts as live oak, toyon, occasionally conifers, annual sow thistle, filaree, bur clover, alfalfa, and various ornamentals near residences. Groups of adults often cluster together under the old shells of scale

insects still attached to green leaves of various hosts and often in the navel end of oranges. This dormant period extends from the first of November to the latter part of March, according to the locality and the altitude. During the winter, sweeping in grass and weeds with an insect net usually reveals a few scattered adults.

Where heavy frosts do not occur both annual sow thistle and prickly lettuce plants may be occasionally found all winter at the margins of orchards, along fence rows, on ditch banks, and the like. On the underside of the larger leaves of these preferred hosts near the ground, adults are found. By the last of March when the mean daily temperature rises to 55°–60° F, the surviving adults gradually concentrate on the preferred hosts. For several weeks they feed, copulate, and lay eggs. At this time the egg stage lasts 15 to 20 days; and by the last of April the first larvae appear in small numbers on these plants and also to a minor extent on other annuals such as poppy, filaree, and bur clover. By the first of May the overwintering adults have nearly all died. About three weeks later the adults of the first spring generation mature. Reproduction continues on the remaining host plants at the margins of cultivated land and to some extent on alfalfa. The larvae of the second generation appear about June 1 and also feed and mature on the wild hosts. As generations overlap considerably throughout the summer, there cannot be said to be distinct periods when any stage in the life history is entirely absent.

When the adults of the second generation emerge from the soil the hosts are beginning to mature and become unfavorable. Thus about the last of June a gradual migration takes place from the native plants to cultivated crops nearby. Certain native plants such as morning-glory, blazing star, and milkweed serve as hosts during the summer. These minor hosts are of small importance, being apparently unsuitable for extensive reproduction.

During July, August, and September the bean thrips appear in injurious numbers on pears. The third, fourth, fifth, and doubtless a sixth generation are passed on the pear. As the pear leaves become tough and fall the larvae die, egg laying ceases, and the adults migrate to suitable protected places to pass the winter.

In general the seasonal cycle is the same in the San Joaquin Valley near the large bean and cotton acreages as in the Lake County pear orchards. In some respects, however, the habits are at variance. Since practically no trees or shrubs are present (fig. 8), the winter is passed almost entirely on annual plants in and about the bean and cotton fields and along roadsides and ditch banks. In areas where the rainfall is less, the mortality is lower. Also, because of higher temperatures in the spring,

reproduction begins sooner; and the migration to cotton and beans begins when the plants come out of the ground. In addition, where peas are grown in the spring in adjacent fields a heavy migration from the drying pea vines (if infested) occurs just as the beans come up. This hazard is encountered also in the Sutter Basin. Reproduction continues, however, also on the preferred native hosts until they mature; and a continual reinfestation of the crop field occurs all summer, particularly where weeds remain green along ditch banks (fig. 8). A heavy infestation on a stand of prickly lettuce adjacent to a bean field may not dam-

Fig. 8.—Prickly lettuce growing on irrigation canal bank at the border of a bean field. To prevent bean-thrips injury, such weed growth should be removed before the beans come up.

age the crop seriously if the native hosts remain green enough to support the thrips until late summer, when the crop is well established. This condition often occurs in seasons with late spring rains. Because of higher mean temperatures there appears to be a seventh generation in the lower San Joaquin Valley. Russell (1921*b*) believed that there were as many as eleven generations in the Imperial Valley.

In the fall, after the bean vines or cotton plants dry up, a large migration takes place to whatever crops or plants are still green. At this time fall-cultivated lettuce, carrots, sugar beets, asparagus ferns, and alfalfa in the vicinity often support a tremendous populaton of adult bean thrips. One generation may be completed on these fall crops; but usually with cooler weather reproduction ceases, and the larvae rarely become abundant enough to be injurious.

Under natural conditions where the bean thrips occurs on its native hosts at considerable distance from cultivated crops, the seasonal peak of abundance is reached in July and drops rapidly after the prickly let-

tuce matures; the adults are then forced to migrate to the remaining few green plants capable of supporting them. One can readily see, therefore, why this insect has become a pest of such irrigated crops as beans and cotton. Also along the irrigation-ditch banks and around pump houses the prickly lettuce often remains green throughout the summer, which allows the thrips to breed up in great numbers. In nearly every case of crop injury in Calfornia the source of infestation is local weed growth, particularly the prickly lettuce and the annual sow thistle.

The situation in Sutter Basin is largely the same as described above; but the initial infestation of crops occurs somewhat later, and the spring build-up on the native hosts is much slower. Where double cropping is practiced, furthermore, late beans are often seriously damaged before they become established. Along the coast the bean thrips is rarely injurious, chiefly because the lower temperatures are less favorable to reproduction.

DISTRIBUTION AND ABUNDANCE IN RELATION TO CLIMATE

Very few thrips have a cosmopolitan distribution or exist under a wide range of climate. The onion thrips (*Thrips tabaci* Lind.) is probably the most extensively distributed economic species in the world. In North America several species of the genus *Frankliniella,* known as the flower, grass, or wheat thrips are scattered irregularly over the southern portion of the continent.

Thrips usually live in what might well be called a microenvironment since they occupy such a small space on leaf surfaces, in soil, or under bark. Thus the climatological data compiled by U. S. Department of Agriculture Weather Bureau stations at various elevations aboveground can be used merely as a comparative index to the varying conditions the bean thrips encounters within its range.

Of the factors that apparently restrict the spread and relative abundance of *Hercothrips fasciatus,* temperature and rainfall are most important. Though either may be a limiting factor, their combined influence and the degree to which they vary from "normal" determine the thrips' local and seasonal abundance.

In California the bean thrips is most abundant in the Sacramento and San Joaquin valleys. Injurious numbers also often appear in certain nonirrigated valleys of the Coast Range, in the Sierra foothills, in the Imperial Valley, and in local areas in southern California (fig. 1).

In hot, dry years thrips injury to beans, cotton, and pears is severe. During such seasons damage is often observed where in normal years the thrips are unimportant (see fig. 1). Summer temperatures of the Weather Bureau stations in various localities throw considerable light

on this point. Following are the average mean temperatures of various California stations for June, July, August, and September, in degrees Fahrenheit:[11]

Sacramento Valley:	° F
Redding	77.8
Red Bluff	75.6
Orland	78.8
Chico	77.2
Willows	76.9
Colusa	73.5
Marysville	75.8
Davis	73.8
Average	*76.2*

San Joaquin:	° F
Lodi	70.6
Stockton	71.2
Merced	76.4
Los Banos	76.5
Fresno	78.0
Coalinga	77.9
Visalia	76.1
Wasco	78.6
Bakersfield	79.3
Average	*76.1*

Sierra Foothills:	° F
Oroville	75.8
Nevada City	65.4
Auburn	73.7
Folsom	75.6
Placerville	68.1
Sonora	73.3
Porterville	78.8
Average	*72.9*

Coast Range (Interior):	° F
Ukiah	68.7
Upper Lake	70.0
Clear Lake (near)	71.1
Napa	65.7
Santa Rosa	64.8
Vacaville	71.8
Hollister	65.2
Average	*68.2*

San Francisco Bay:	° F
Antioch	74.3
Crockett	65.8
Kentfield	64.2
San Francisco	59.2
Berkeley	61.3
Palo Alto	64.2
San Jose	65.3
Average	*64.9*

Coastal sections:	° F
Crescent City (near)	58.0
Eureka	55.4
Santa Cruz	62.7
Watsonville	61.3
Santa Barbara	65.2
Oxnard	62.9
Long Beach	68.5
San Diego	66.7
Average	*62.6*

Southern California:	° F
Tehachapi	71.1
San Fernando	71.2
Los Angeles	69.1
Pomona	71.1
Fontana	72.0
Santa Ana	69.4
San Bernardino (near)	73.6
Riverside	72.8
El Cajon	71.1
Indio	89.6
Imperial	87.5
Average	*74.4*

One notes that the extreme range of normal mean temperature of the summer months (June-September) in the great valleys varies from

[11] Based on the normal established up to 1932 and calculated by averaging the normal monthly mean temperature of each month as given in: United States Department of Agriculture Weather Bureau. Climatological Data 22 No. 13. California Section. 1935.

70.6° F at Lodi to 79.3° at Bakersfield. The average for eight stations in the Sacramento Valley is 76.2°; for nine stations in the San Joaquin Valley, 76.1°.

In 1933, the writer showed that the optimum temperature range for feeding (of the adults) is between 77° and 90° F (constant temperature). One can therefore easily understand why this insect is a crop pest in the great valleys, other conditions being favorable.

For comparison and for additional evidence of the influence of temperature on abundance, the following data are presented. Except in Nevada City the bean thrips occurs abundantly in the Sierra Foothill localities given in the foregoing tabulation. The summer temperatures of these foothills, though somewhat lower than those of the valleys (average 72.9° F for seven stations), are high enough to be favorable.

At Vacaville and in Lake County the bean thrips is very abundant. The average summer temperature for the interior coast-range stations selected is 68.2° F. When the temperature is above normal, *Hercothrips fasciatus* proves injurious in Contra Costa County at Concord, Walnut Creek, and near Martinez. The summer temperatures of Weather Bureau stations adjoining the San Francisco and Suisun bays is 64.9°. One should note the high temperature of Antioch, only a short distance from the three localities in Contra Costa County mentioned above.

The bean thrips occurs in all the coast counties but never in very large numbers; the temperatures along the coast are far below optimum (average of 62.6° F). Inland from Long Beach, however (Russell, 1912*b*), truck crops are sometimes injured in many parts of Los Angeles County. *Hercothrips fasciatus* occurs throughout southern California; the temperatures of various stations there are given for comparison. Occasional injury is reported in Orange, Riverside, and San Diego counties. The southern localities, particularly the Imperial Valley, usually have summer temperatures within the optimum range, the average of all southern stations being 74.4.

Apparently, in California localities where normal mean temperature for the summer months is about 70° F or above, the bean thrips are numerous enough to be injurious if other conditions are favorable. With normal mean summer temperatures from about 64° to 70°, crop injury may occur in very hot, dry seasons. Districts enjoying mean summer temperatures below approximately 64° are rarely if ever concerned with this crop pest. The summer rainfall, usually less than 1 inch, is of no concern as a limiting factor in California since only heavy showers of driving force are detrimental to the thrips population.

In addition to California, the bean thrips have been numerous enough

to be injurious in Idaho, Utah, Wyoming, and Arizona. Summer weather conditions in or near the localities where the pest is known to occur in these states offer some interesting comparisons.

Judging from the study of this insect in California, conditions favor summer infestations in Idaho and Utah, particularly in dry years. Injury has been frequent in these states in areas (table 3) where annual crops are grown. Though in western Oregon summer conditions are not very favorable, weather records indicate that this thrips could become injurious in certain eastern parts such as at Huntington. As far as the writer knows, no injury has been reported from Oregon. In the summer of 1933 the writer observed minor infestations near Reno, Nevada. Even though the bean thrips has never been noted in the Yakima district of Washington, conditions there appear favorable. Future distributional records may include the Washington area. In 1935, for the first time, *Hercothrips fasciatus* was found in Wyoming; at Powell, where injury to beans occurred, summer weather conditions might be said to be on the borderline of favorableness. In Colorado the bean thrips, though known to occur at Palisade, is not yet recorded from any crop hosts. Possibly in the Grand Valley, west of Palisade, in exceptionally dry years this thrips may build up, although no damage has been reported. In this locality (Palisade) summer-temperature conditions appear favorable despite a normal summer rainfall of nearly 4 inches—apparently about

TABLE 3

AVERAGE MEAN* TEMPERATURE OF VARIOUS STATIONS FOR THE MONTHS OF JUNE, JULY, AUGUST, AND SEPTEMBER, WITH THE NORMAL RAINFALL FOR THESE MONTHS

Locality	Temperature, degrees Fahrenheit	Rainfall, inches	Locality	Temperature, degrees Fahrenheit	Rainfall, inches
Yakima, Washington†	67.1	1.59	Agricultural College, New Mexico†	77.2	5.28
Ashland, Oregon	65.5	2.56	Houston, Texas†	81.8	16.80
Huntington, Oregon	72.4	1.77	Laredo, Texas†	85.8	8.01
Colusa, California	73.5	0.67	State College, Mississippi†	79.1	15.51
Reno, Nevada	65.3	1.02	Baton Rouge, Louisiana†	80.1	21.03
Lewiston, Idaho	69.0	3.46	Birmingham, Alabama†	78.0	17.27
Twin Falls, Idaho	65.3	1.81	Daytona Beach, Florida	79.9	21.43
Logan, Utah	67.2	3.40	Atlanta, Georgia†	75.8	15.83
Ogden, Utah	68.7	2.96	Clemson College, South Carolina	76.0	18.94
Palisade, Colorado	71.8	3.93	Clarksville, Tennessee†	75.0	14.26
Grand Junction, Colorado	72.6	3.10			
Powell, Wyoming	64.0	3.07			
Phoenix, Arizona	86.3	2.84			

* Based on the normal established up to 1932 and calculated by averaging the normal monthly mean temperature of each month as given in: United States Department of Agriculture Weather Bureau. Climatological Data 22 No. 13. 1935.

† The bean thrips is not definitely known to occur in these states.

the maximum that a bean-thrips infestation can withstand. In the northern limits of its distribution severe winters, the lack of favorable hibernating quarters, and the absence of suitable host plants undoubtedly prevent the increase of this insect.

It seems strange that the bean thrips has never been taken in New Mexico. At Agricultural College, for example, according to Weather Bureau records, it could survive easily, even though the summer rains (normally 5.28 inches) would probably prevent an epidemic. Its occurrence in Texas has never been definitely determined. The normal summer rainfall is probably too high to allow any appreciable build-up in the truck-farming areas of this state. Near Laredo, however (table 3), in dry years injury may become evident if the insect does occur there at present or in the future.

Watson (1920, 1921) reported the bean thrips from Florida: "It seems probable that the insect is a native species which only occasionally becomes abundant enough to cause material damage." Near Daytona Beach (at Seabreeze), where the original collection was made, the normal summer rainfall is over 21 inches. J. G. Watts of the South Carolina Experiment Station wrote in correspondence (August 26, 1936): "We have never had to my knowledge any appreciable infestation of this species in South Carolina. It occurs throughout the state and can easily be found, but we do not consider it as an economic pest in any way." At Clemson College the normal summer rainfall is 18.94 inches.

As was stated above, many records from other states (Tennessee, Mississippi, Alabama, and Louisiana) need verification. If, however, the bean thrips can regularly survive conditions in South Carolina and Florida, one would expect to find it distributed widely though not abundantly throughout the southern states (table 3).

The general conclusion is that the bean thrips may become epidemic if other conditions are favorable, in localities having a normal mean summer temperature of about 70° F or above. With lower summer temperatures, especially those ranging from about 65° to 70°, injury may be anticipated in hot, dry years. Localities enjoying normal mean summer temperatures below 65° will rarely, if ever, suffer an outbreak. A high summer rainfall will limit the increase of this thrips in many areas having favorable temperatures, particularly in the large group of southern states. The minimum amount of precipitation during the summer months that appears to prevent *Hercothrips fasciatus* from becoming abundant is about 4 inches. Insufficient distributional data are at hand to make an injury-zone map for North America as has been done for California. Little further can be said concerning the ecology of this insect

until we have more information concerning its behavior in areas other than California, the state where it has been the most intensively studied.

CONTROL

The control of the bean thrips, as of most economic insects, is based upon a knowledge of the life history and the seasonal cycle. Natural control by parasites and predators is of but little consequence.

Natural Enemies.—Like most insects the bean thrips has its natural enemies. Chief among them are the following insects: the internal parasite, *Thripoctenus russelli* Cwfd. and the predators *Chrysopa californica* Coq., *Orius* (*Triphleps*) *insidiosus* var. *tristicolor* White, *Hippodamia convergens* Guerin, *Aeolothrips fasciatus* (Linn.), and *A. kuwanaii* Moulton. Unfortunately none of these is sufficiently numerous or active to control the bean thrips effectually.

In southern California the parasitism of *Hercothrips fasciatus* by *Thripoctenus russelli* has been reported to be as high as 70 per cent (Russell, 1912*b*). Under field conditions the writer has never observed such a high degree of parasitism. In the seasons of 1929–1931, when the bean thrips was very abundant, the percentage of parasitized larvae was about 5 per cent. In the summer of 1930, among about 10,000 larvae collected in the field for life-history studies, only 0.9 per cent were found to be parasitized. There appears, however, to be a gradual seasonal increase in the number of parasites, reaching a maximum in the late fall.

This parasite is a very minute chalcid of the subfamily Tetrastichinae. It was first discovered by Russell (1912*a*) at Compton, California, in 1910. The adult parasite oviposits in the larger (second instar) bean-thrips larvae. The length of its egg-and-larval stage averages about 7.5 days; of its pupal stage, about 14 days, during the summer. Adult parasites held in cold chambers as long as 5 days at 30° F constant temperature oviposited after removal from the low temperature. Parasitized bean thrips larvae usually molt to the prepupal stage but never reach the pupal stage.

Several years ago Karl Schmidt, working under the direction of R. N. Chapman of Hawaii, reared the bean-thrips parasite, *Thripoctenus russelli,* in considerable numbers at Riverside, California, and shipped them to Hawaii in an attempt to control the onion thrips. The plan proved unsuccessful.[12]

The adults and nymphs of the anthocorid, *Orius insidiosus tristicolor,* feed on the bean thrips larvae all season but rarely reduce them noticeably. Apparently this predator prefers the larvae of the flower thrips and onion thrips to the bean thrips. Both adults and larvae of the con-

[12] Unpublished data of Hawaiian Pineapple Producers' Coöperative Association.

vergent ladybird beetle feed commonly on the larvae of the bean thrips and are often found in company with the larvae of the green lacewing, *Chrysopa californica* Coq.; but neither appreciably reduces the thrips population. The larvae of *Aeolothrips fasciatus* (Linn.) and *A. kuwanaii* Moulton occasionally prey upon the bean-thrips larvae also but are far from abundant, particularly in the summer, when the bean thrips are most prevalent. The adult predacious thrips will feed on all stages of the bean thrips if confined with them.

Russell (1912*b*) observed the larvae of the syrphid fly (*Sphaerophoria sulphuripes* Thomson) feeding on bean-thrips larvae. In addition a nematode and several predacious mites are known to attack *Hercothrips fasciatus*. For a more detailed account of natural enemies see Bailey (1933).

Chemical Control.—Among the earliest control recommendations for the bean thrips, Klee (1887) suggested "sulphur washes, similar to those used against the red spider." In 1910 Bremner recommended a spray composed of tobacco extract, 1 part to 50 gallons of water. Merrill (1912) obtained control with a flour-paste spray. Russell (1912*b*) advised "a solution of 2¾ per cent nicotine, diluted at the rate of 1 part to 60 parts of water in a 6 per cent distillate-oil emulsion" with fish-oil soap for fruit trees. The same writer believed spraying impractical for alfalfa, cotton, and beans; he strongly recommended clean cultivation. Essig (1915) stated that "tobacco decoctions and lime-sulfur or oil emulsions give very good results." DeOng (1921) and co-workers approved of irrigation to aid plant growth and advised nicotine sulfate and soap for beans. Jacobsen (1927) reported that the most satisfactory insecticide used experimentally on pears was "a combination of light miscible oil with nicotine sulfate. Ground pyrethrum and pyrethrum extracts furnished practically as effective control." Lewis (1928, 1929) obtained best results on pears with a drenching spray made according to the following formula:

Light neutral white oil emulsion	1 gallon
Nicotine sulfate	½ pint
Casein spreader	½ pound
Hydrated lime	½ pound
Water	100 gallons

Whale-oil soap alone (5 pounds to 100 gallons), summer oil alone at 2 per cent, or pyrethrum did not give a satisfactory kill, according to Lewis, who also advised removing all wild lettuce from orchards and roadsides.

L. M. Smith (1930), who conducted extensive control experiments on pears in the Berryessa Valley (Napa County), summarized his work as

follows: "The kill obtained by oil was considerably greater than that of sulfur, and the kill obtained by oil and nicotine was greater than that from oil alone." Sulfur (30 pounds per acre) produced considerable injury to small twigs, leaves, and fruit. The outstanding observation was that trees sprayed with oil retained their leaves much longer than the check or sulfured trees. Highly refined summer oil at 2 per cent with ½ pint of nicotine sulfate per 100 gallons of spray was used.

Smith also wrote that, while weed control gave variable results, "on one large ranch, a strict program of weed eradication was followed, and apparently the thrips injury was delayed a week or ten days." Irrigation of infested trees gave a "94.8 per cent reduction in the number of thrips emerging from the soil."

Stokes (1931), working on pears in Lake County, used 1 pint of nicotine sulfate and "a good grade of medium summer oil, 1½ gallons to 100 gallons of water." He recommended that "the spraying should not start before 6:30 or 7:00 o'clock in the evening or continue later than 7:00 in the morning," since spraying with an oil in midday injures pears in hot weather. The first application is usually needed about the middle of July. Stokes recently informed the writer that in orchards where this spray was applied an excellent control of the pear bud mite was also obtained. Mackie (1936) reported that "50 per cent cryolite and 50 per cent sulfur furnished considerable relief" among beans in Sutter County.

Growers have employed insecticides including nicotine sulfate, pyrethrum, rotenone-bearing compounds, fluosilicates, sulfur, and hydrated lime from time to time against the bean thrips, but with inconsistent results. Much careful experimental work must be done before it can be said which material (or combination) is most effective.

Recently, however, the writer made some preliminary field trials with some of the newer dust mixtures. Small field plots of beans, 10 rows wide and 75 feet long, were treated in Stanislaus, Solano, and Sutter counties. Only one application was made with a rotary hand duster at the rate of approximately 25 pounds per acre. Untreated strips of four rows were left between plots. The leaves were taken at random from the four center rows, and counts of the larvae on the underside only were made at 24-hour intervals. This method of counting, it is believed, gives a very accurate index of the real control, since all the materials used controlled the thrips rather effectively on the upper side of the leaves. The adults are too active to be counted accurately. The results are given in tables 4, 5, and 6 and are based on larval counts.

In the field at Patterson the mixture of pyrethrum and sulfur and also the cube gave the best control. In the second trial (near Davis), the

pyrethrum mixture again gave the best control but up to 48 hours only. Much higher populations of thrips were available for treatment in the Sutter Basin field; and here again the pyrethrum mixture most effectively reduced the larval population. In plot 2 (table 6) the greater reduction may have been the result of a greater repellent action by the diatomaceous earth. The plants in this plot also appeared to mature

TABLE 4

RESULTS OF BEAN-THRIPS CONTROL EXPERIMENTS ON PINK BEANS; PATTERSON, JULY, 1936

Plot No.	Material	Average number of larvae alive per leaf,* before treatment and at specified intervals after treatment				
		Before treatment	12 hours	1 day	2 days	5 days
1	Nicotine dust (4 per cent actual nicotine and hydrated lime as diluent)	....	4.4	1.0	2.3	2.4
2	Pyrethrum ("Activated A"=0.5 per cent pyrethrins) 50 per cent plus sulfur (325 mesh) 50 per cent (0.25 per cent pyrethrins in complete dust mixture)	....	7.8	3.7	1.7	0.5
3	Rotenone (0.75 per cent). Diluent, talc with lampblack†	....	5.1	7.5	5.8	3.2
4	Check (no treatment)	9.8	8.6	13.4	7.9	4.8
5	Cryolite undiluted ("Alorco"=83 per cent Na_3AlF_6)	....	6.6	8.8	4.6	4.7
6	Barium fluosilicate ("Dutox"=80 per cent $BaSiF_6$)	....	4.8	3.2	2.8	2.1
7	Cube (5 per cent rotenone) 10 per cent, plus sulfur (325 mesh) 90 per cent (0.5 per cent rotenone in complete dust mixture)	....	7.2	3.6	3.2	0.8
8	Check (no treatment)	7.3	11.5	8.5	6.8	8.9

* Based on 50 leaves per plot.

† This was a proprietary mixture and it has been impossible to ascertain the exact proportions of the ingredients; the source of the rotenone was timbo root.

somewhat faster, so that many of the thrips were forced to leave. Evans (1933) reported that "pyrethrum powder, even when mixed with sulfur in the proportions of 1 part of pyrethrum to 10 parts of sulfur, was shown to retain its strength as a repellent for two days" against the apple thrips (*Thrips imaginis* Bagn.) at high summer temperatures in Australia. This worker also stated that while the nicotine dusts "killed thrips quicker than pyrethrum, their effect was not as lasting." His conclusions are borne out by the data given above. Besides acting as a repellent, however, the pyrethrum mixture killed many of the newly emerged larvae up to 5 days after application in the field under normal summer weather conditions.

There are two primary reasons why satisfactory chemical control on such crops as peas, beans, and cotton is difficult and very often unsatis-

factory. First, growers do not notice the presence of the thrips until the lower leaves begin to dry up and fall. By that time a heavy infestation is built up in the field; and when control is attempted, two or three applications about a week apart are necessary. The eggs and pupae are not killed by the insecticides. The hatching of the larvae and the emergence of the adults continue for about a week after the application even though all the adults and larvae are killed at the time of treatment. The second reason why control is often ineffective is the difficulty of dusting

TABLE 5
Results of Bean-Thrips Control Experiments on Baby Lima Beans; Near Davis, August, 1936

Plot	Material	Average number of larvae alive per leaf* before treatment and at specified intervals after treatment					
		Before treatment	1 day	2 days	3 days	4 days	5 days
1	Rotenone (0.75 per cent). Diluent, talc with lampblack†	....	8.9	12.6	10.9	5.8	9.5
2	Cryolite ("Alorco"=83 per cent Na_3AlF_6), undiluted	....	6.7	8.2	5.4	10.1	8.0
3	Pyrethrum ("Activated A"=0.5 per cent pyrethrins) 50 per cent, plus sulfur (325 mesh) 50 per cent (0.25 per cent pyrethrins in complete dust mixture)	....	2.3	2.7	4.5	6.6	6.8
4	Check (no treatment)	6.1	11.9	19.4	13.7	16.2	14.4

* Based on 25 leaves per plot.

† This was a proprietary mixture and it has been impossible to ascertain the exact proportions of the ingredients; the source of the rotenone was timbo root.

thoroughly the undersides of the leaves, particularly on large leafy plants. The majority of the thrips on the upper side are usually killed by most of the contact dusts. The colonies of larvae on the underside, however, are very difficult to reduce materially. Often, too, in large fields that are irrigated regularly, the material cannot be applied with ground machines. Still another factor contributes to the lack of effective control by chemicals alone: if the weed hosts are allowed to remain in and about the fields (and orchards) continual reinfestation occurs all summer.

The chemical-control measures for this pest on deciduous fruit trees and on such annual crops as peas, beans, and cotton are necessarily different. The spraying of beans and cotton is generally considered impractical. Most pear growers whose orchards are in districts where the bean thrips is injurious are not equipped to apply dusts.

Because of the Hawaiian restrictions cited above, Woglum (1931) experimented with fumigation. He found that the hydrocyanic acid "gas generated from ⅔ of an ounce of sodium cyanide to the 100 cubic

feet of space in a gas tight fumigatorium for an exposure of 35 minutes would eradicate the bean thrips in wrapped and packed citrus fruits." On the basis of his work this dosage was written into the Hawaiian regulations. The method has been regularly employed since 1930. Later studies by Woglum and Lewis (1936) have shown that nitrogen trichloride, "at a concentration of about 1.4 mg per liter of air, with an exposure for at least four hours, was necessary for 100 per cent kill." This dosage was above the tolerance of oranges to injury. Although no other country has a specific quarantine against the bean thrips, practically all citrus exported from California is fumigated for this and other pests.

TABLE 6

RESULTS OF BEAN-THRIPS CONTROL EXPERIMENTS ON BABY LIMA BEANS; SUTTER BASIN, AUGUST, 1936

Plot	Material	Average number of larvae alive per leaf* before treatment and at specified intervals after treatment		
		Before treatment	1 day	5 days
1	Pyrethrum ("Activated A"=0.5 per cent pyrethrins), undiluted	25.0	11.6	14.3
2	Pyrethrum ("Activated A"=0.5 per cent pyrethrins) 50 per cent, plus diatomaceous earth 50 per cent (0.25 per cent pyrethrins in complete dust mixture)	36.0	8.4	4.6
3	Cryolite ("Kryocide"=90 per cent Na_3AlF_6), undiluted	14.2	11.6	7.6
4	Cryolite ("Kryocide"=90 per cent Na_3AlF_6) 50 per cent, plus sulfur (325 mesh) 50 per cent (45 per cent Na_3AlF_6 in complete dust mixture)	8.6	8.3	5.6
5	Cryolite ("Alorco"=83 per cent Na_3AlF_6) 50 per cent, plus sulfur (325 mesh) 50 per cent (41.5 per cent Na_3AlF_6 in complete dust mixture)	18.2	8.4	6.0
6	Check (no treatment)	14.0	27.5	25.6

* Based on 25 leaves per plot.

Cultural Control.—The most important consideration in controlling this pest is the source of the infestation—namely, weeds—and their elimination. In every case observed by the writer during the past eight seasons the source was weed growth, particularly prickly lettuce in or near the fields and orchards. As soon as the annual crop plants come up, the adult bean thrips start moving into the fields from the marginal areas. In very dry years this migration is early and is often severe enough to set back the young plants. Thus an early spring campaign of weed control is important. The writer has demonstrated that, in the San Joaquin Valley, with the generous coöperation of the officials and growers of Stanslaus County particularly, this thrips can be satisfactorily controlled by weed control alone. In Stanislaus County in

1933–36, weed control was practiced, and results were carefully checked. Count areas were established in 1935 at 0, 50, 100, 250, and 500 yards from the margin of the bean fields, the initial point of infestation. Ten leaves were selected at random at these points at each side and in the center of bean fields, both where weed control was being practiced and where it was not undertaken (the checks). Only the larvae on the undersides of the leaves were counted because the adults move about too much, because the infestation starts on the underside, and because some unit count had to be established. The variation in the size of the leaves was

TABLE 7

Bean-Thrips Control Experiments on Beans; Westley, California, 1935

Date of count	Average number of larvae per leaf		Per cent reduction in infestation	Date of count	Average number of larvae per leaf		Per cent reduction in infestation
	Field with no weed control	Field with weeds removed before beans came up			Field with no weed control	Field with weeds removed before beans came up	
June 14......	10.4	2.5	75	July 26......	4.5	0.6	86
June 21......	1.5	0.1	93	August 2....	3.5	1.3	63
July 5.......	3.0	0.5	83	August 9....	5.3	0.6	88
July 12......	1.4	0.03	97	August 16...	9.0	0.7	92
July 19......	0.7	0.2	71				

a variable not eliminated. Thus 150 leaves from each field constituted the basis for each count, and nine counts were made at weekly intervals during the summer. Two typical fields were carefully checked throughout the season, with the results shown in table 7.

The counts taken at the above-mentioned distances from the margins of the fields indicated a high initial infestation. Also, though the counts were higher at the borders of the fields about the first two weeks after the beans were up, the thrips spread rapidly over the entire area. A complete list of counts would add little to the discussion. The average number of larvae per leaf on June 14 was high also because only two or four leaves were present on a plant. As the plants put out more leaves the proportionate number of thrips per leaf dropped. When the irrigation was stopped and the plants began to mature, the infestation rose rapidly until the time the plants lost their succulence. The seasonal infestation in the district reached its peak on August 16. The average seasonal reduction of the infestation (table 7) from the weed-control operations alone in one field (approximately 400 acres) was 83.1 per cent, which with adequate irrigation protected the plants satisfactorily.

In some districts, the native-host elimination may become a supple-

mentary aid because weed control is difficult in brushy or hill country or on land surrounded by sloughs, rice fields, and the like.

In large areas of contiguous plantings of beans or cotton, the control of the bean thrips depends upon removing all the prickly lettuce and annual sow thistle at the margins of the fields, roadsides, ditch banks, and railroad tracks (figs. 8, 9, 10) at least two weeks before the bean plants come through the ground. All eggs and larvae on the weeds are killed, and the adults must either leave or starve. This work may be done

Fig. 9.—Weed control practiced at the edges of bean fields as here illustrated eliminates the source of bean-thrips infestation.

by hand, by disking, oiling, burning, or sterilization. *All the principal host plants must be destroyed and kept down during the growing season.* This recommendation cannot be too strongly emphasized, for satisfactory control depends almost entirely upon it. Large acreages may thus be protected for a few dollars as compared with the large expenditure necessary in applying insecticides later in the season.

Overhead irrigation with the so-called "rain machines" has under certain conditions held the bean thrips in check. Two years ago in Sutter Basin two adjoining bean fields, one irrigated by the overhead method and the other by ditches, offered a fine comparison. When the plants were small the sprinkling kept the thrips down to a minimum, but as the plants grew it became less efficient. The bean thrips never became abundant under the sprinkling method; but a common species of grass or flower thrips, *Frankliniella occidentalis* (Perg.), increased in numbers, though not enough to be important. The adjacent field irrigated by the usual ditch method suffered considerable loss from the bean thrips and supported a very few flower thrips. Fields which are only subirri-

gated are usually injured more severely because the top soil remains dry and warm. Under such conditions the bean thrips multiplies rapidly; and if the plants are not well established and growing well, premature defoliation and stunting often result.

Weed control in deciduous fruit orchards, where the bean thrips is a pest, is fundamentally the same as with annual crops and is just as important. When the covercrop is plowed under in the spring, any prickly lettuce or sow-thistle plants remaining around the base of the trees or

Fig. 10.—Small fields of string beans grown in brushy areas make removal of native hosts of bean thrips difficult.

at the edges of the orchard should be hoed up. Otherwise the thrips population builds up on these plants and sooner or later migrates to the trees. During the spring and summer these weeds and also morning-glory and poppy, which occasionally serve as hosts, should be kept down in and about the orchards in districts where the bean thrips is a pest.

Resistant Varieties.—The only information on the relative resistance of bean varieties to thrips injury has been obtained from field observation. Apparently beans of the kidney type are more severely injured than limas. As W. W. Mackie, Associate Agronomist in the Experiment Station, has observed,[13] "All bush beans are usually more easily damaged than the viny types." Certain exceptions, however, make bean varieties difficult to classify according to their degree of resistance. In general, Large Limas, Baby Limas, Black Eyes, and Red Kidneys are somewhat resistant to bean-thrips injury. Pinks, Pintos, Bayos, and Cranberries usually suffer considerable damage if other conditions favor the insect. Infestations can be largely prevented, controlled, or checked by good

[13] In correspondence of August 4, 1936.

cultural methods. Thus an extensive breeding program for developing thrips-resistant varieties is unlikely to become necessary.

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